ANALYSIS AND EXPERIMENTAL INVESTIGATION OF MECHANICAL VIBRATION IN SWITCHED RELUCTANCE MOTOR

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***Abstract*—Electric motor or the hybrid electric vehicle of switched reluctance motor has the wide torque and speed range. Due to the flux strengthening and magnetic saturation, double salient structure causes the high range of torque ripple, mechanical vibration and acoustic noise. This severe can be overcome by using different control techniques like conventional PI control which are efficiency and cost effective. The control of torque ripple by using both controller techniques are simulated by using Matlab/Simulink and the outcome of mechanical vibration and acoustic noise from both the controller gets analyzed in Graphical programming language, LabVIEW tool. This graphical language gives the efficient and accurate results in terms of mechanical vibration and acoustic noise.**

Keywords—Proportional Integral Controller (PI), Mechanical vibration, Switched reluctance motor (SRM), Time domain analysis, Root mean Square (RMS).

I. INTRODUCTION

The switched reluctance motor has the good efficiency and good tolerable condition at high speed when compared to other high industrial motor drives like BLDC, PMSM motors. In order to reduce the mechanical vibration various literature papers have been described. In this paper they proposed to reduce the hardware complexity by using microprocessor or micro controller to achieve the steady state torque. By achieving the steady state torque here the torque ripple gets reduced completely [1]. In order to reduce the vibration by using some measurements, [2] the shaker and force hammer tests are used for measuring crucial parameters like the frequency and damping ratio. And again this model gets verified by using experimental accuracy. To control the switched reluctance motor here in linear and nonlinear model, [3] the PI control, Hysteresis Control and voltage control has been described and the hardware complexity are also reduced by using microprocessor/micro controller/DSP processors. To reduce the torque ripple factor [4], the stator and rotor has increased by using its finite element analysis and by using MAGNETO software the parameter values are calculated to achieve the reduction of torque ripple. This paper [5] is just used to investigate about the vibratory modes and the fault tolerant system into the switched reluctance motor by using its two frames, smooth frames and ribbon frames. They detailed analyzed it by using theoretical predictions. In this paper [6], due to Vibration and acoustic noise the application of switched reluctance motors (SRMs) has been reduced. Here they construct eight computational models by varying the respective structural forms to investigate the influence of radiating ribs on the mechanical resonant frequencies. Finally, they derive an optimal structure of the radiating rib to lower the acoustic noise level of SRMs and dissipate heat. Here [7], they compared the 12/8 and 6/4 SRM by using the two-dimensional (2D) transient magnetic finite-element analysis (FEA) and they get compared in both time and frequency domains. As they concluded that the vibration and noise are dramatically reduced for 12/8 SRM during experiments. [8] Comparing to the PSPICE for simulation of SRM drives, here the POWERSYS and SIMULINK are used in order to avoid the complexity of getting simulation results. [9] The fuzzy logic control is used to reduce torque ripple by injecting its additional current to its phase current but the fuzzy logic control algorithm implementation will requires more complexity [10] this paper is used analyze the torque ripple, vibration, noise level in PMSM drives using MATLAB and LabVIEW and this paper gives full detail about the reduction of vibration and noise level both in software and experimental verification by using accelerometer.[11] By investigating the mechanical vibration and acoustic noise, the occurrence of vibration level gets reduced by reducing the radial force and tangential force and also the misalignment of inductance gets reduced. [12] This paper has the clear concept of analyzing the input signal both in time and frequency domain and also used to understand the concept of mechanical vibration and acoustic noise in Switched Reluctance Motor. [13] Here the lyanopov function based direct torque controller is used to reduce the torque ripple factor by using with its variable feedback gain loop. Here the tracking of torque ripple is easier and its easier to minimize the torque ripple factor.[14]] In this paper by using PWM controller in switched reluctance motor the steady state conditions have been analyzed. But by using PWM controller the negative current will produce enormously. [15] By investigating the mechanical vibration and acoustic noise, the occurrence of vibration level gets reduced by reducing the radial force and tangential force and also the misalignment of inductance gets reduced. [16] This vibration which occurs in the interior permanent magnet motor is due to the changes of phase angle of being applied current arising from flux weakening control. The magnetic force is analyzed using the Maxwell stress tensor method, and the vibration induced by the application of a rotating magnetic force is analyzed using the mode superposition method. It shows that the use of flux weakening control could increase magnetically induced vibrations because of increases in the tangential magnetic force. [17] In this paper by using PWM controller in switched reluctance motor the steady state conditions have been analyzed. But by using PWM controller the negative current will produce enormously. [18] By using fuzzy logic controller the speed error can be reduced by using its state evaluation control rules derived from a rough formulation of the sliding mode control of the drives. [19] From this paper the torque ripple disadvantages has been reduced by using different torque controller method like PI controller and DTC controller to have steady state torque response. Generally this motor have a four fundamental element namely: Power Converter, Position Sensor, and Logic Circuit and Switched reluctance motor. Although the switched reluctance motor has strongest in its variable high speed condition, simple in construction, it has some weakness like high torque ripple, mechanical vibration and acoustic noise condition. To trim down this kind of high torque ripple at most, here the PI is implemented. The reason for this high torque ripple in switched reluctance motor gets appeared due to the improper unaligned and aligned inductance region. The purpose of using PI controller is to rise the speed response and also it removes the steady state error obtained from its input. But by using this conventional controller the mechanical vibration and acoustic noise cannot be reduced effectively. Only by implementing the trial and error method in PI controller the torque ripple gets condense as much as possible and here in which the torque ripple, mechanical vibration and acoustic noise can be reduced as much as possible The end result of mechanical vibration and acoustic noise from both the controller was analyzed by using LabVIEW program.

II. CONTROLLERS TECHNIQUES FOR SRM DRIVES

A. Conventional controller:

PI controller method is often used in industrial control and practical systems due to its simple error reducing control system and it is used to achieve the required gain results by using the parameter tuning methods. PI controller has the controlled parameter of (Kp , Ki) to achieve the best control performance. Kp controller is used to sum the error and Ki controller is used to integrate the erred signal,

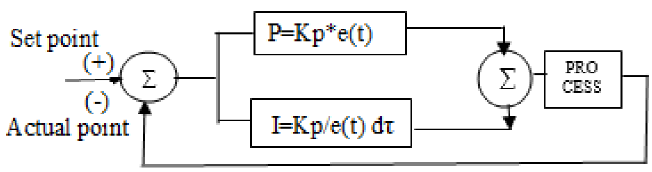


Fig-1: Feedback control system using PI controller

$$K_P \Delta + K_I \int \Delta \, d\tau \longrightarrow \quad (1)$$

Where Δ is the error or deviation of actual measured point (PV) from the set point (SP).

$$\Delta = SP - PV \longrightarrow \quad (2)$$

The PI controller is used to reduce the close loop systems error and thereby it increases the system response speed. If the speed of the system gets improved, then the torque ripple in switched reluctance motor are also gets improved for every different variable load and speed conditions. As the PI controller eliminates error and increases the speed response, the flux and speed is given as the input to the pi controller through sum and output of PI controller is given as gate signals to the converter called as the asymmetric H-bridge converter to control the each phases of SRM drive.

The following are the gain values for PI controller, Kp=1.0863, Ki=0.0573

III. PROPOSED SCHEME

A. Block Diagram for Proposed Scheme:

The response torque is calculated from the SRM machine terminal voltage and currents. The projected torque is compared with reference torque and by the sampling time (N), by the way the torque ripple is calculated, using the formula (3),

$$T_{ripple} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(T_e(i) - T_{av})^2} \longrightarrow \quad (3)$$

Whereas,

Tripple=Torque ripple,
Te=actual value,
Tav=Reference value,
N=sampling period,

From the controller, the torque ripple output waveform is directly related to the mechanical vibration is one of the relations which drive down the vibration occurred in the PI controller fed SRM. The velocity is a vibration amplitude factor is a rate of change of displacement of vibration signal. It is the most common machine vibration measurement. It is also measured in mm/Sec (True RMS value). This parameter is sensitive to the vibration frequencies ranging from 500 to 60,000 CPM (cycles per minute).

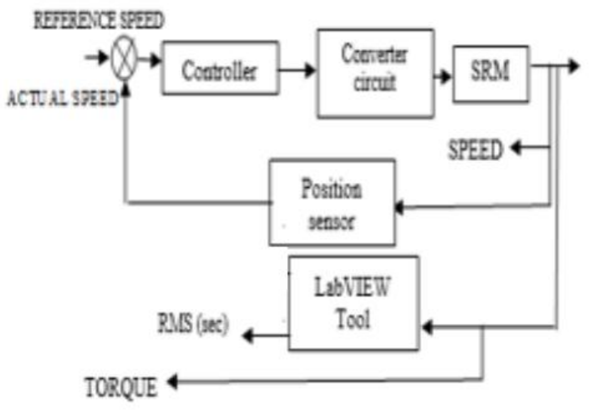


Fig-4: Block diagram for PI using LabVIEW tool

By using the Lab VIEW software for analyzing the mechanical vibration level in time domain to analysis and it gives the real time signal and separate the signal characteristics like the value of amplitude. Alternatively here the frequency domain measurement is also used the various information like amplitude, phase, power spectrum, Fast Fourier Transform (FFT) are obtained by this measurement. This analysis gives additional information about the signal and signal through which is generated.

IV. SIMULATION AND RESULTS:

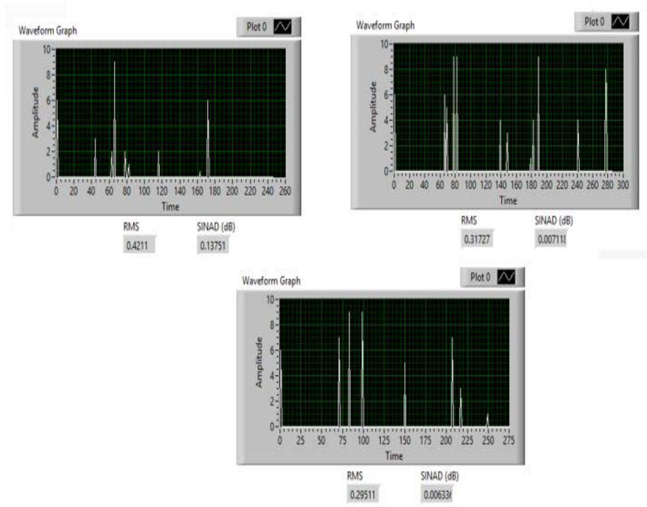
A. Time domain measurement:

The time domain measurement it gives the amplitude of the signal at that time during which the signal was sampled. Using single or double integration the acceleration of vibration signal, and the analysis of vibration signal is performed. This vibration signal is measured in Root Mean Square (true RMS) value. In Distortion measurement, the signal in noise ratio distortion (SINAD) is performed from the related torque waveform.

Load	Speed(rpm)	RMS	SINAD
0.5Nm	1000	14.562	11.342
	3000	10.456	14.346
1 Nm	1000	11.905	10.421
	3000	10.994	12.234
2 Nm	1000	10.457	14.321
	3000	9.4927	15.288

Table-2: Quantitative Analysis Table for Time Domain Measurement

From this table we clear came to know that DTC controller have removed the mechanical vibration and acoustic noise as much as possible.



In time domain measurement table- 1. shows the analysis of vibration level in term of velocity in the RMS (mm/sec) and the acoustic noise level in terms of Signal in Noise ratio and Distortion (SINAD) (dB) for a choice of different speeds and load variation. Velocity is the rate of change of displacement of vibration signal that would be in true RMS value. As per the ISO 2372 standard guidelines for vibration measurement, it should be in the acceptance ranges for all no load, and at load condition. From the analyzed value of time domain measurement,the vibration level at a speed of 3000 rpm for 2Nm load condition is 0.2951 mm/sec and a 0.0063 dB.

The following chart describes about the vibration severity chart ISO 2372 which clearly able to understand the level of vibration for every speed and load condition.

Vibration level chart

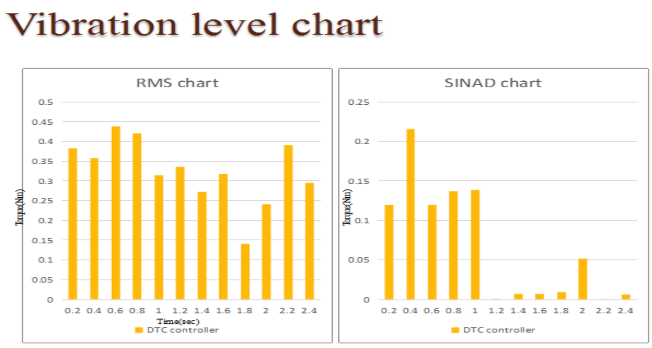


Fig-7: RMS and SINAD chart for vibration level

From the analyze of time domain measurement at a high speed of 3000rpm with load condition of 2Nm has the RMS value of 0.2951mm/sec and SINAD value of 0.0063 dB and for frequency domain measurement, average and total noise value is 0.1768 dB and 0.2925 dB. These vibration analyses are useful for evaluating the current machine condition and diagnosing the fault linked with the operational machine.

V. EXPERIMENTAL DISCUSSION

The following fig-14 are my experimental setup to analysis the vibration and acoustic noise in switched reluctance motor by using vibration analyzer.

Fig-15: Experimental setup to measure vibration analyzer.

This experimental results have been shown for various three axis for different load and speed changes. There are horizontal, vertical and axial axis of bearings. X, Y, Z are the three axis of placing accelerometer.

A. Vertical axis:

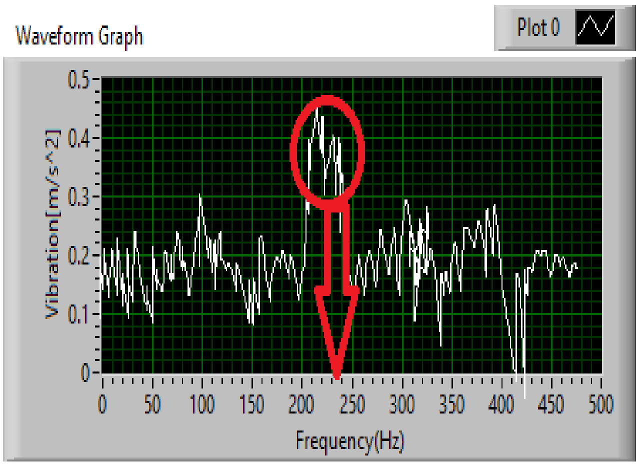


***Fig-16**: Vibration level chart for Vertical Axis.*

Compare to other axis of accelerometer, here the vertical axis has the high vibration due to placing accelerometer near by the motor. Here the frequency ranges between 200Hz to 250Hz.

B. Horizontal axis:

In horizontal axis here the vibration level are very low compare to all other axis because the accelerometer are placed away from the motor. Here the frequency ranges between 150Hz to 200Hz.

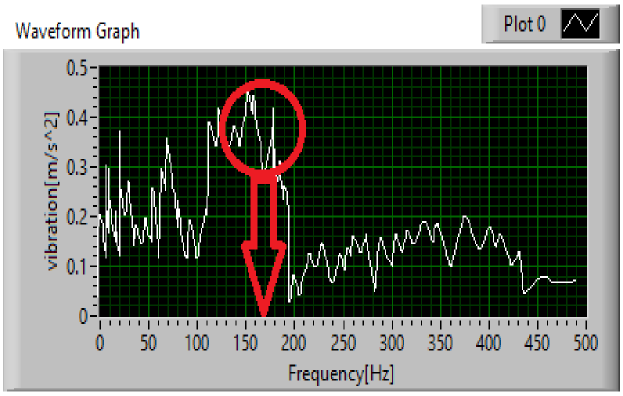


***Fig-17**: Vibration level chart for Horizontal Axis.*

C. Axial axis:

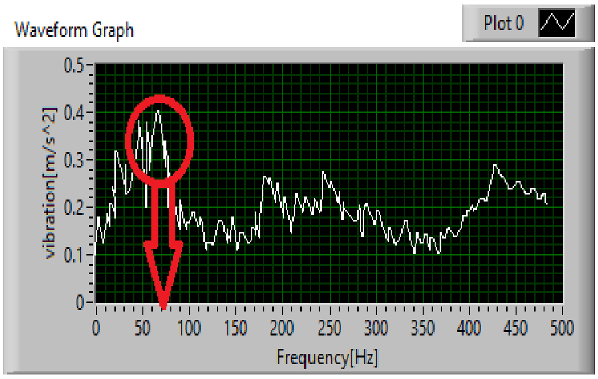


***Fig-18**: Vibration level chart for Axial Axis.*

In axial axis here the vibration level are medium as compare to all other axis because the accelerometer are placed somewhat nearer to the motor. Here the frequency ranges between 50 Hz to 100 Hz. Therefore in axial axis this vibration level is too low when compared to other axis.

VI. CONCULSION

In this work, the mechanical vibration in PI controller fed SRM has been analyzed in time domain measurement In time domain analysis, the Root mean Square (RMS) has been calculated for a choice of different speed and load changes. The mechanical vibration and acoustic noise has been analyzed for a choice of different speeds of 300rpm, 1000rpm, 2000rpm, and 3000rpm for load of 0.5Nm, 1Nm, and 2Nm. Form the time domain measurement, the analyzed mechanical vibration . The conclusion made good from the analyses of time domain was completed by Lab VIEW. With this development of graphical language it gives high performance, flexibility and accurate information about the signal.

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